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Report of the Workshop on the Ecological Interactions between Shrimp and Bottomfishes, April, 1980

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I. INTRODUCTION

Edward F. Klima

The Shrimp and Bottomfish Workshop was convened in an attempt to determine the best research approach to understanding and defining the interactions between penaeid shrimp and bottomfish communities in the Gulf of Mexico. The shrimp fishery of the Gulf of Mexico is the most valuable fishery in the continental United States. The major shrimp trawl fisheries are located in the northcentral and northwestern Gulf of Mexico, overlapping the major concentrations of bottomfishes (primarily sciaenids) in the northcentral Gulf. The fisheries are not mutually exclusive, since each takes incidental catches of the other. Shrimp and bottomfishes are found at different abundance levels on the inshore and offshore fishery grounds but utilize similar inshore nursery areas. Recruitment of both species groups overlaps in time and space. The impacts of the inshore and offshore shrimp fisheries on bottomfish biomass are unknown. Furthermore, at this time the predator/prey relationships between shrimp and bottomfishes on the continental shelf are poorly understood.

For the above reasons and the need to implement fishery management plans for both shrimp and bottomfishes, it is imperative to develop a firm understanding of the ecology of these two major species groups. In the immediate future, management plans will be approved for both the shrimp and bottomfish fisheries. Since there are possibilities of conflict between these two major fisheries, an understanding of the targeted species and their interactions is important to the development of wise management strategies. The Gulf of Mexico Fishery Management Council has fully identified the research priorities related to the management of both shrimp and bottomfishes and has stressed the importance of interactions between species groups. Therefore, it is not the intent of this workshop to alter research priorities related to fisheries management, but rather to identify and prioritize the research approach necessary to understand the interactions between shrimp and bottomfish communities in the Gulf of Mexico.

To accomplish the objective of outlining a rational ecological research program for shrimp and bottomfishes, the workshop was divided into background and working sessions. Basic information available for analysis of shrimp and bottomfish resources was delimited, and a set of pertinent questions identifying and prioritizing ecological research objectives was formulated. The list of questions included:

1. What are the density distributions of various shrimp and bottomfish species?
2. What is the extent of overlap between the density distributions of shrimp and bottomfish stocks in time and space?
3. How does each fishery impact the stocks of the other, and what are the magnitudes of these impacts?
4. What are the trophic relationships between penaeid shrimps and dominant bottomfish species (such as croaker, spot, sand seatrout, and silver seatrout)?
5. What are the major prey and predator species in the inshore and offshore areas that can or may affect both shrimp and bottomfish abundance?
6. If an effective excluder and/or separator trawl is developed and bottomfishes are not caught incidentally, what impact would this new technique have on the ecosystem and shrimp and bottomfish stocks in the northern Gulf community?

II. Shrimp and Groundfish Research Priorities

Albert C. Jones

Problems and issues of the Gulf of Mexico shrimp and groundfish fisheries have been identified in the Fishery Management Plans (FMP) prepared for these species by the Gulf of Mexico Fishery Management Council. At this time, the draft plans for both fisheries have been reviewed and adopted by the Council. The shrimp plan has undergone public hearings submitted to the National Marine Fisheries Service (NMFS) for approval by the Secretary of Commerce. The groundfish plan is being prepared as a framework FMP, prior to public hearing. (Editorial note: NMFS designates these demersal fishes as "bottomfish" while the Council's FMP employs "groundfish" in the title; therefore, "groundfish" is used throughout this section.)

Although the shrimp and groundfish plans are separate, there are similarities in the two resources and their fisheries. Shrimp and groundfish occupy similar environments (both are demersal animals, occur in estuaries during their postlarval and juvenile stages, and migrate offshore where the adults spawn). Shrimp and groundfish are fished by similar fleets and, in many cases, by the same vessels, where groundfish are a bycatch. Because of these similarities, it is possible that management of these resources may eventually be combined within a single plan. In recognition of these similarities and the need to develop a broad understanding of community ecology, the Southeast Fisheries Center (SEFC) research programs on shrimp and groundfish were combined in 1979.

Information needs identified for the shrimp and groundfish fisheries fall into four broad areas: data base, economics, status of stocks, and ecology. One immediate need is for quantitative data with which to make sound management decisions. Recommendations made recently by the SEFC for changes to the shrimp statistics system will provide an adequate data base. A good description of the total catch (including size and species composition) and the fishing pattern matrix (including standardized effort) are fundamental for biological and economic analyses.

A second immediate need is to describe the economic impacts of the Texas closure and Tortugas Sanctuary management measures. The immediate economic needs concern the impact of regulations on people. While these impacts may be more imagined than real, they are real enough to the persons affected and need to be evaluated. The three principal management measures in the Shrimp FMP are (1) Texas closure, (2) Tortugas Sanctuary, and (3) stone crab line closure.

Some questions relating to the management measures have direct answers, for example:

1. Will the Texas closure result in an increase in size and availability of shrimp?
2. What will be the impact of the Texas closure on the catch per unit effort (CPUE) off Louisiana as a result of a higher concentration of vessels?
3. Will the shift in shrimp vessel fishing patterns overload the Louisiana shore processing facilities?

In the immediate time frame, the before and after situations for each of the regulations can be described and managers can then make a decision as to whether this is good or bad.

Long-term needs include economic and stock assessment analyses and predictions of the consequences of alternative harvesting strategies. We already have a good deal of information from historical studies: neither shrimp nor groundfish appear to be in immediate danger. Nevertheless, continuation of present studies in this area will provide answers to basic questions:

1. What is the mortality rate of brown shrimp and, therefore, what is the optimum biological size for harvest in the brown shrimp fishery?
2. What is the growth rate of croaker and, therefore, what is the optimum exploitation strategy for this resource?

A third long-term need is for an understanding of the ecological relationships between shrimp and groundfish so that the effects of fishing and the environment on the ecosystem can be predicted. It is this third long-term need that is being addressed by this workshop. A community ecology approach is required to provide answers to some of the most basic questions:

1. Why are groundfish catches down?
2. If shrimp catches drop, what might the cause be?

3. How can we predict the impact of the continuing loss of estuarine habitat and changes in freshwater discharge?

These questions, although very difficult to answer, are among the most important facing managers of these resources and require that we devote our best efforts to supplying an understanding of the shrimp-groundfish ecosystem.

The following prioritized list of research required to update FMPs (Table 1) was extracted from the Gulf Shrimp and Groundfish FMP, as identified by the Gulf of Mexico Fishery Management Council. The FMPs should be consulted for more detailed description of the research.

Table 1. Recommended Priority Order for Shrimp and Groundfish Research Delineated in Gulf Fishery Management Plans.

I. HIGHEST PRIORITY RESEARCH (Immediate Implementation - Long-Term Duration)

A. Shrimp FMP

1. Develop information on mortality, age, and growth parameters.
2. Determine the impact of seasonality of fishing and consequences of dislocation of portions of the commercial fleet with emphasis on Mexican and Texas closures.
3. Study the amounts and types of shrimp habitat and their relation to production.

B. Groundfish FMP

1. Establish an inshore/offshore monitoring system to determine estuaries of major importance, seasonal variation in abundance, timing of migration, migration routes, and prediction of annual stock strength.

II. VERY HIGH PRIORITY RESEARCH (Long-Term Duration)

A. Shrimp and Groundfish FMPs

1. Trawl bycatch utilization and reduction study, including development and testing of modified trawls.
2. Population dynamics of shrimp/groundfish complex

B. Shrimp FMP: Economic study of shrimp fishery and principal species in relation to determining optimum economic yield.

C. Groundfish FMP: Monitor fish/shrimp ratios to estimate discard catch on an annual basis and determine effect of different gear, time of day, season, target species, area, etc.

III. HIGH PRIORITY RESEARCH (Deferred Implementation)

A. Groundfish FMP (Short-Term Duration)

Study effects of salt boxes on stocks, fishing operations, and habitat.

B. Shrimp and Groundfish FMPs (Long-Term Duration)

1. Examine problems associated with developing adequate law enforcement.
2. Improve coordination and communication among data

gathering and analysis programs.

IV. MEDIUM AND LESSER PRIORITY RESEARCH (not arranged in priority order)

A. Shrimp FMP

1. Determine the economic impact of uncontrolled shrimp imports.
2. Determine the biological and economic effects of discarding undersized shrimp.
3. Examine problems of limited jurisdiction.
4. Determine the effect of fishing the shrimp nursery grounds.
5. Increase understanding of industry, market structure and behavioral relationships among economic units.
6. Determine boat inventories.
7. Develop methodologies for measuring marine recreational fisheries benefits.
8. Delineate various user interest groups within the Gulf shrimp fishery.
9 Determine political, legal and enforcement problems present in Gulf regional shrimp management.
10. Annually assess overwintering populations in the Gulf of Mexico.
11. Measure the change in vessel efficiency in the Gulf of Mexico shrimp fishery.

B. Groundfish FMP

1. Test the capability of midwater trawling for the harvest of croaker and other groundfish in the northcentral Gulf.
2. Study the feasibility of seasonally protected nursery areas.
3. Assess the use of trawl samples to project stock abundance and biomass estimates.
4. Analyze the contribution of the groundfish industry to the community economy.
5. Determine total retail value of groundfish products.
6. Conduct cost and return study of groundfish fishery.

7. Determine fish/shrimp ratio for recreational shrimp fishery.
8. Continue resource surveys of primary area by NMFS vessels.

III. BACKGROUND - SHRIMP/BOTTOMFISH

1. Biology and Life History of Penaeid Shrimp

James M. Lyon

REPRODUCTION

Ripe females, larvae, and postlarvae of the genus *Penaeus* are known to occur year round in the northern Gulf of Mexico with spring, summer and fall abundance peaks from 60 fathoms to nearshore (Lindner and Anderson, 1956; Jones et al., 1964; Christmas et al., 1966; Baxter and Renfro, 1967). The potential of multiple spawning by one female has been shown by Cummings (1961). Peak recruitments of postlarvae into the estuaries are seasonal: brown shrimp (*P. aztecus*) in spring, white shrimp (*P. setiferus*) throughout summer, and pink shrimp (*P. duorarum*) in late summer and fall (Joyce and Eldred, 1966; Baxter and Renfro, 1967; Gaidry and White, 1973).

AGE AND GROWTH

As there are no hard parts in the shrimp body, present techniques for age and growth studies are limited to monitoring and mark-recapture studies. Through mark-recapture studies, the longevity of penaeid shrimp is known to extend beyond two years (Baxter, 1971).

Growth rates of juveniles in estuaries have been shown to vary widely (Knudsen et al., 1977) and are directly correlated with temperature (Phares, M.S.). Growth rates in offshore waters are also variable (Christmas and Etzold, 1977). Males grow more rapidly than females and both sexes exhibit more rapid growth in southern (south of 26° latitude) than in northern latitudes (Parrack, 1979). Mark-recapture studies linking Louisiana estuarine and offshore areas have demonstrated that monthly cohorts of white shrimp grow at differing rates (Parrack, 1979).

FOOD HABITS

Food habits of penaeid shrimp change from the algae and zooplankton diet of oceanic larval forms (Pearson, 1939; Ewald, 1965) to benthic feeding as postlarvae. Once benthic feeding has begun in estuaries, shrimp have been described as omnivores (Viosca, 1928; Weymouth et al., 1955; Darnell, 1958) and as selective particulate feeders (Lindner and Cook, 1970). Further diet changes occur as the juveniles move from the estuarine shoreline to the open bay where active predation on benthic organisms begins (Jones, 1973). Substrate detritic material is ingested through adult stages (91 to 142 mm; Darnell, 1958).

HABITAT

A direct relationship exists between yields of penaeid shrimp and vegetated estuarine areas (Turner, 1977). Juvenile penaeids are more abundant in and adjacent to vegetated areas (Mock, 1967; Trent et al., 1972) than in altered, nonvegetated areas. Penaeids prefer substrate with vegetative litter and cover rather than bare areas (Williams, 1958).

Offshore areas of terriginous, silty substrate near major watersheds appear to be the preferred white shrimp habitat (Osborn et al., 1969). Pink shrimp habitat offshore is related to the harder calcareous sandy bottom occurring along Florida and southern Texas coasts (Grady, 1971), and brown shrimp occupy the intermediate habitats.

2. The Shrimp Fishery

Stephen L. Hollaway

HARVESTING

The current trend in offshore shrimp fishing vessels is toward larger "Florida-type" trawlers of steel or wood, double-rigged to tow two to four otter trawls simultaneously. Large hydraulic winch systems and sophisticated electronic gear are used extensively. The inshore live bait shrimp fishery uses shallow draft boats or outboard-powered skiffs towing 12- to 25-ft otter trawls. Other inshore harvesting equipment includes channel nets, butterfly nets, and pushnets.

SEASONS AND LOCATIONS

Brown shrimp (*Penaeus aztecus*) are distributed throughout the Gulf of Mexico, with a major concentration off the Texas coast. Peak production is from June through October, generally from depths of 11 fm and greater. White shrimp (*P. setiferus*) are distributed from northwest Florida to south Texas, with the major concentration occurring off the Louisiana coast. Peak production occurs during the fall from waters up to 10 fm. Pink shrimp (*P. duorarum*) are distributed almost continuously throughout the Gulf of Mexico, with the major U. S. fishery located in the Tortugas-Sanibel, Florida, area (Osborn et al., 1969). Production is high from fall to spring mainly between 11 and 20 fm. The live bait shrimp industry in the Gulf of Mexico is based on these major species of *Penaeus*, species composition depending upon locality and season.

BYCATCH

Incidental catch of finfish in the Gulf of Mexcio amounts to an estimated 34% to 43% of the total catch from shrimping operations off Texas. Fish-shrimp ratios are estimated to be from 1:1 to 7:1 with a yearly average of 4:1 (Blomo and Nichols, 1974). The species composition of the bycatch is primarily Atlantic croaker (*Micropogonias undulatus*), longspine porgy (*Stenotomus caprinus*), and Gulf butterfish (*Peprilus burti*) (Moore et al., 1970; Bryan and Cody, 1975). Sciaenids made up 75% of Gulf bottomfish landings during the period 1959-1963 (Roithmayr, 1965). Discard rates for undersized shrimp range from 22% to 45% by weight of the total catch (Baxter, 1973). Discarding practices are influenced by several factors: (1) the availability and value of small shrimp, (2) the method of grading landings, and (3) minimum size regulations. In the inshore bait fishery, Atlantic croaker, pinfish (Lagodon rhomboides), and Gulf menhaden (Brevoortia patronus) comprise the major portion of the incidental finfish catch.

3. Ecological Questions Concerning the Discard of the Bottomfish Bycatch of Shrimp Trawls

Joan A. Browder

Penaeid shrimp and demersal fishes are major components of the estuarine-coastal shelf ecosystem of the northern Gulf of Mexico. To the extent that we have information about them, they appear to share similar habitats, may depend upon similar food resources, and may feed common predators.

They also are harvested by a common gear, with shrimp the target species and bottomfish the unwanted bycatch which is primarily discarded by shrimpers. Approximately 200,000 to 400,000 metric tons of bottomfish are harvested each year from the northcentral Gulf of Mexico in commercial and recreational fishing operations in estuaries and on the shelf. The weight of the fish bycatch averages approximately 14 times the weight of the shrimp catch (Gulf of Mexico Fishery Management Council, 1980).

Important ecological as well as economic and social questions should be addressed with regard to the regular practice of harvesting and discarding such a large biomass from an ecosystem. The ecological questions are as follows:

1. How does bottomfish removal affect shrimp production and how does shrimp removal influence bottomfish?
2. Does removing bottomfish from competition for food (if any exists) increase the availability of food for shrimp to the extent that shrimp yield is significantly increased?
3. Does the discard of bottomfish significantly increase shrimp production by increasing the production of food for shrimp, either directly by feeding them, their prey, or their predators, or indirectly through remineralization which could stimulate primary production?
4. Do bottomfish prey on shrimp to the extent that eliminating bottomfish by harvesting and discarding significantly reduces predation pressure on shrimp?
5. Does the elimination of bottomfish as an alternative prey source increase or decrease predation pressure on shrimp?

6. Does the elimination of bottomfish as a prey source affect the growth and abundance of coastal migratory predator species such as mackerel?

7. Is there a major waste of natural energy in the ecosystem from the misdirection of high quality material (suitable food for man or higher predators) into low quality uses (food for microbes)? If so, what are the implications for the ecosystem, fisheries, and man?

Although the problem of a bycatch is not unique to the shrimp fishery and occurs in other fisheries wherever gear is non-selective, the discard of the Gulf coast shrimp fishery probably is not exceeded or even approached in magnitude by that of any other fishery anywhere in the world. A possible exception is the shrimp fishery off the Atlantic-Caribbean coast of South America, where similar ecological conditions exist. A program to promote the utilization of the bycatch is operating in that area.

4. Reduction of Shrimp Bycatch

W. R. Seidel

The shrimp industry has a significant impact on the bottomfish resource. Shrimp vessel bycatch is either utilized or discarded without attempts to conserve the fish by releasing them alive. Conservation of the resource has been investigated in two study areas: (1) directed study (separator trawl), and (2) reducing sea turtle capture (excluder trawl).

Separator Trawl (1976-1977)

The overall objectives were to keep shrimp loss at less than 10% and to reduce the bycatch as much as possible within the shrimp loss restriction. A variety of separator configurations had beed tested, the best design effecting approximately a 57% overall bycatch reduction with an associated shrimp loss of 8%. This design had a selected species reduction of: croaker - 70%; spot - 71%; seatrout - 58%. The difficulty in reducing the bycatch in the Gulf of Mexico is the broad size ranges of both shrimp and fishes. Even in deeper water (20 fathoms), 35 to 40% of the fish catch may be composed of fish as small or smaller in length than the predominant length of shrimp in the catch.

Excluder Trawl (1977-Present)

The objectives of this project are to significantly reduce sea turtle capture in shrimp trawls without reducing the shrimp catch. Therefore, the excluder panels may not decrease the finfish bycatch. The excluder panel is a 26-inch stretch mesh which completely closes the mouth of a trawl, headrope to footrope. Preliminary results indicate a reduction of finfish bycatch by only 12 to 25%.

Conservation of bycatch in shrimp trawls has been listed as a very high priority, long-term research need in the Groundfish Management Plan (GMP) which targets a 50% reduction in finfish bycatch as a significant level for conservation. This level is probably achievable with the separator trawl but not with the excluder trawl. However, the excluder trawl is intended mainly as a regulatory device in areas where sea turtle captures are a problem.

In general, there is potential for significantly reducing bycatch in shrimp trawls. More directed work will be required to design the most operationally effective trawl. In addition, species, areas, and times of the year have to be considered for further studies. The most serious limiting factor on a separator trawl's effectiveness is the size of fish for which separation is desired. The seasonal size of the fish throughout their range needs to be related to the separator trawl development. Generally, therefore, techniques can be developed to meet GMP goals offshore but much more difficulty will be encountered during early-in-the-year shrimp seasons when the associated size of finfish is small.

5. Areas of Low Dissolved Oxygen, Gulf of Mexico

Sammy M. Ray

The occurrence of extensive areas of oxygen-deficient or hypoxic bottom waters (<2.0 ppm dissolved oxygen) on the inner continental shelf of the Gulf of Mexico is not uncommon. Hypoxic waters have been noted on the central shelf off Louisiana (Harris, Ragan and Kilgen, 1976; Harris, Ragan and Green, 1978; Ragan, Harris and Green, 1978; Ragan et al., 1978; Bedinger, 1980), on the western shelf off Louisiana in the West Hackberry area (Landry and Armstrong, 1980), and on the shelf of the upper Texs coast (Harper et al., M.S.)

Most reports of hypoxic bottom water and associated mortality and/or paucity of benthic and demersal organisms have been directly related to high flows or flooding from major river systems during warm periods of the year. Large volumes of fresh water overriding the saline bottom waters cause stratification of the water column which is intensified by the lack of vertical mixing during periods of calm weather. This phenomenon has been noted most often in regions influenced by the Mississippi River system (Mississippi and Atchafalaya Rivers), one of the most productive areas for shrimp and bottomfish in the Gulf of Mexico. This natural phenomenon is possibly of major importance in dealing with the environmental factors that influence the abundance and distribution of shrimp and bottomfish stocks.

The temporal and spatial extents of hypoxic waters have just recently been documented. For example, oxygen-deficient waters formed a layer 2 to 7 m thick at contours ranging from depths of 6 to 33 m on Louisiana's central shelf for 11 months in 1973-74 (Ragan, Harris and Green, 1978). The area impacted was seasonally variable, ranging from 93% of the sampling area in July to 27% of the area in December. Trawling in the oxygen-deficient areas yielded few or no mobile organisms. These hypoxic waters coincided with the second greatest annual flow of the Mississippi River system (a mean flow of 1,097,000 cubic feet per second per day for 1973) between 1899 and 1979 (Gunter, 1979).

A more recent occurrence of hypoxic bottom waters on the central Louisiana shelf was reported by Bedinger (1980). Hypoxic waters were reported up to 45 km offshore and at depths of up to 27 m in August and

September, 1978, which potentially extended up to 300 km west of the main distributaries of the Mississippi River.

Harper et al. (M.S.) documented the first occurrence of hypoxic bottom waters on the Texas shelf apparently due to high freshwater inflow from river systems of the upper Texas coast. In June and July, 1979, areas of hypoxic water, dead or moribund benthic organisms, and reduced nekton densities were detected on the shelf off Freeport, Texas. Sampling off the mouth of the Brazos River in July at depths of 9 to 33 m and extending offshore for about 50 km detected a thermocline-halocline at about 10-m depths, above which the dissolved oxygen content (D.O.) was >4.0 ppm but below which the D.O. was <2.0 ppm. It was <1.0 ppm near the bottom at some stations. No hypoxic waters were detected after August 31, 1979. Harper et al. concluded that at least 250 km of the upper Texas coast, and possibly a part of the Louisiana coast, were affected in the summer of 1979.

Hypoxic bottom waters on the continental shelf may seriously affect annual recruitment, migration, population distribution, food supply, and mortality of the shrimp and bottomfish. Consideration of this phenomenon would seem to be of critical importance, since the shelf region of the northern Gulf of Mexico that is most likely to be affected by hypoxic conditions related to influx of large volumes of fresh water (from river systems such as the Mississippi) coincides with a major area of shrimp and bottomfish production.

6. Sumary of Information on Shrimp Dynamics

Michael L. Parrack

Much of the research effort of the Southeast Fisheries Center's Shrimp Management Program has been directed at determining optimum harvest size using yield-per-recruit techniques. This approach requires estimates of shrimp growth and mortality rates. Currently available information on growth and mortality of white, brown and pink shrimp is summarized in Tables 1 and 2.

There are a large number of published growth models for shrimp, mainly derived from mark/recapture experiments. Seasonal differences in growth of wild populations have been found for pink and white shrimp and are expected for brown shrimp. Spatial and year-to-year variations in growth rates have not been well documented.

Estimates of natural mortality rates (M) vary by a factor of 27, implying that either M is naturally variable or many of the values overestimate M due to sophisticated analyses of simple mark/recapture data. Life span is dimensionally equal to the reciprocal of the total mortality coefficient (Z); therefore, the reciprocal of the longest time at large from mark/recapture data is an index of Z and thus an approximation of M. Several adult brown shrimp released offshore were at large for 14 months and one was at large 31 months; thus, an approximation of M is .03 to .07. Several juvenile white shrimp marked and released in recent studies were at large for 6 to 10 months; thus, an approximation of M for these shrimp is 0.1 to 0.2.

Estimates of fishing mortality rates (F) also span a wide range reflecting, in part, seasonal shifts of fishing effort, variations in experimental biases, and variable catchability coefficients. A positive correlation between F and effort for the Tortugas pink shrimp fishery has been found (Parrack et al., M.S.).

Studies of the migration patterns of brown and white shrimp are currently in progress (Brunenmeister, M.S.). Brown shrimp recoveries have tended to exhibit patterns of directed migration across the U. S. - Mexico border (Table 3), whereas recoveries of white shrimp released in inshore Louisiana waters reflect very little directed movement offshore.

Immediate needs clearly center on obtaining reliable estimates of M for brown and white shrimp and on documenting seasonal patterns of growth for brown shrimp. Future concern will involve studying the variations of growth and mortality in time and space and in response to environmental variation. Ultimately, the yield-per-recruit approach must be linked with description and prediction of shrimp recruitment, thus allowing shrimp dynamics to be considered on an absolute stock size basis.

Table 1. Existing estimates of shrimp mortality (per week, Base e). Z = total mortality coefficient, F = fishing mortality rate, M = natural mortality rate.

Species	Z	F	M	References
Brown	0.27	0.06	0.21	Klima (1963)
		0.020-0.315		Neal (1967)
	0.993-1.243			McCoy (1968)
	0.571	0.206	0.364	McCoy (1972)
White	0.46			Klima (1963)
	0.14-0.27	0.06-0.19	0.08	Klima and Benigno (1965)
	0.164-0.226	0.104-0.131	0.041-0.121	Klima (1974)
Pink		0-0.4	0.07	Parrack (M.S.)
		0.09	0.27	Iverson (1962)
	0.76-1.51	0.96	0.55	Kutkuhn (1966)
	0.22-0.27	0.160-0.227	0.024-0.061	Berry (1967)
	0.11-0.18	0.03-0.07	0.08-0.11	Costello and Allen (1968)
	0.11	0.09	0.02	Berry (1969)
	0.612	0.337	0.280	McCoy (1972)
	0.317-0.350			McCoy (1972)

Table 2. Pink, brown, and white shrimp population studies.

NATURAL MORTALITY RATES

Pink Shrimp	Brown Shrimp	White Shrimp
Iverson (1962)	Klima (1963)	Klima and Benigno (1965)
Kutkuhn (1966)	McCoy (1972)	Klima (1974)
Costello and Allen (1968)		
Berry (1970)		
McCoy (1972)		
Parrack et al. (M.S.)		

GROWTH RATES

Pink Shrimp	Brown Shrimp	White Shrimp
Iverson and Jones (1961)	McCoy (1968)	Lindner and Anderson (195
Kutkuhn (1966)	McCoy (1972)	Klima (1964)
*Berry (1967)	Chavez (1973)	Klima (1979)
McCoy (1972)	Purvis and McCoy (1974)	*Phares (M.S.)
*Parrack et al. (M.S.)	Parrack (1979)	

RELATIONS BETWEEN FISHING MORTALITY AND FISHING EFFORT

Tortugas Pink Shrimp Parrack et al. (1979)

RATES OF MIGRATION

Texas-Mexico Autumn Brown Shrimp Brunenmeister (M.S.)

*Study considered the seasonality of growth.

able 3. Brown shrimp migration across the U.S. - Mexico Border, 1978 (from Brunenmeister, M.S.). Speeds are in km/day, directions are in degrees from true north.

		Northward Migrants			Southward Migrants		
elease onth	Release Location	Average Speed	Average Direction	% Going North	Average Speed	Average Direction	% Going South
ugust	Pt. Aransas, TX	4.74	45.6	59	2.69	177.5	41
eptember	Pass Jesus-Maria, Mex.	3.47	25.5	27	3.66	194.9	73
ctober	Pt. Aransas, TX	3.58	23.7	38	2.43	180.2	62

6. The Gulf Shrimp Fishery - Yield Statistics

Charles Caillouet

The annual catch of brown shrimp (heads off) for the Gulf states (excluding Florida) during the past 24 years (1956 through 1979) has average 67 million pounds. During the first ten years following 1956, production fluctuated between 38 million pounds in 1961 and 68 million pounds in 1959. During the past 13-year period (1967 through 1979), the annual brown shrimp catch has fluctuated between the record landings of 99 million pounds in 1967 to a low of 56 million pounds in 1973. In 6 of the last 13 years, the annual brown shrimp landings exceeded 80 million pounds.

At least 80% of the brown shrimp are landed in Texas and Louisiana, and, excepting 1969, the Texas landings have exceeded the Louisiana landings since 1956. Since 1975 the disparity between the Texas and Louisiana catches appears to be decreasing, while Alabama has increased production.

The average annual Gulf states brown shrimp landings of 78 million pounds for the past 13 years have been considerably higher than the average annual catch of 55 million pounds recorded for the 11 years prior to 1967. This marked increase in reported landings for brown shrimp in recent years may be due to increased effort and/or improved catch reporting procedures.

Although pink shrimp contribute to the landings, all grooved shrimp are treated as browns. Pink shrimp landings in Texas and Louisiana represent catches made mainly in Mexican and Florida waters. Pink shrimp production was on the order of 1 to 5% of brown shrimp production from 1976 through 1979.

The annual catch of white shrimp (heads-off) averaged 32 million pounds from 1956 through 1979, ranging from 10 million pounds in 1957 up to 46 million pounds in 1963 and 1978. During the period 1956-1966, the annual white shrimp catch averaged 27 million pounds and ranged from 10 to 46 million pounds. Annual landings from 1967 through 1979 averaged 37 million pounds with a narrower range of 24 to 46 million pounds. The difference betwen the two periods was due to a series of years (1956 to 1962) with low landings. Louisiana landings averaged 62% of the white shrimp catch, while Texas supplied an additional 30%. Contributions by each state to total landings have been relatively constant since 1956.

8. Bottomfish Resources, Gulf of Mexico

Elmer J. Gutherz

Bottomfish resources in the Gulf of Mexico comprise a complex faunistic assemblage of about 180 species of fishes. This assemblage does not include the reef fishes but is rather that group of oceanic and estuarine-dependent species found in the northcentral Gulf from the bays and sounds out to about 50 fm. Biomass estimates based on offshore surveys by the National Marine Fisheries Service (NMFS) have ranged from about 31,000 metric tons (mt) in 1973 to about 128,000 mt in 1978. Since 1976, biomass estimates and commercial landings have decreased. Overall species composition throughout the grounds has not changed significantly; however, croaker abundance east of the Mississippi Delta appears depressed. This report, although addressing bottomfish stocks, will restrict itself to the six dominant species found in the fishery. These six species collectively account for approximately 75% of the biomass. Relative abundances of the six species (croaker, spot, sand and silver seatrout, catfish and cutlassfish) are shown in Table 1 for 1972 to 1978. In addition to the six defined estuarine-dependent species, the oceanic longspine porgy is an important component of the bottomfish stocks on the western Louisiana and Texas shelf.

Of the defined species, only croaker and spot have portions of their life histories documented. Life history information including age and growth, fecundity and spawning, food preference, abundance, distribution, early life history and mortality of these two species has been documented in the Groundfish Management Plan. Little is known of the other species beyond abundance, distribution, and some aspects of the early life history.

Satisfactory age and growth techniques have not been defined for tropical species because of the protracted spawning periods, differential growth rates, fast growth, and high rate of natural mortality. Age and growth schemes have been suggested for croaker and spot; however, validation is lacking for the techniques utilized. At present, most growth hypotheses are based on length-frequency analyses rather than interpretation of hard parts (scales and otoliths). Several investigators have recently begun to look at the daily growth patterns in the otoliths of spot and croaker which may validate the length-frequency schemes.

Spawning times have been reported for all species except longspine porgy, with croaker and spot defined as winter spawners, sand seatrout as spring spawners, catfish and cutlassfish as summer spawners, and silver seatrout as fall spawners. Catfish spawning must be considerably more protracted than originally estimated, since large numbers of small catfish (estimated at about 50 mm) have been collected as late as January off Mobile Bay in 5 to 7 fm. Fecundity is not known for any of the Gulf species. It has been estimated for croaker based on east coast specimens.

Trophic analyses have been conducted to some extent for all 7 species, but most of the data are from estuarine areas. Generally, few penaeid shrimp are eaten in estuaries although penaeids occasionally occur frequently in catfish stomachs. The offshore data show little predation on penaeids by croaker, longspine porgy, and cutlassfish. There may be other bottomfishes which exert a heavier predation pressure on shrimp.

Faunal distribution is variable with about 30% of the fish fauna residing east of the Delta and 70% west of the Delta. Since 1976, the proportion of croaker in the total catch east of the Delta has dropped markedly while remaining relatively stable west of the Delta. Survey data have not indicated a displacement of species east of the Delta. Biomass distributions remain fairly constant east of the Delta with highest catches generally made off Mobile, Ship Island, and the Breton Sound areas. Biomass distributions appear more variable west of the Delta, with significant quantities of fish found from Grand Isle to Ship Shoal. At times, large concentrations of sciaenids are found further west off Trinity Shoal in depths less than 10 fm.

Sciaenids are generally found in turbid waters over soft mud bottoms, except seatrouts which are frequently seen in the clearer oceanic waters. Summer distributions show that stocks are predominantly found in depths less than 10 fm, with a significant portion of the stock consisting of young-of-the-year fish entering the fishery. Offshore movement starts in the fall and continues into winter when stocks are most frequently seen in depths of 15 to 30 fm. Large croakers (exceeding 40 cm TL) are found in depths up to 50 fm off the Mississippi River and west of the Delta throughout the year. With the advent of warmer water in the spring months, fishes move onto the inshore grounds.

At present, little is known of the impact of environmental variation on stocks in the estuaries and sounds. Success of year classes may be determined in egg/larval stages offshore or in larval/juvenile stages in the estuaries and may be strongly correlated with changing meteorological conditions. These factors undoubtedly affect shrimp stocks as well as bottomfish stocks.

An industrial bottomfish fishery was established in the northern Gulf of Mexico in 1952. This fishery began by utilizing the stocks of bottomfish discarded by the shrimp fishery and effort was primarily expended east of the Delta in depths less than 15 fm. By the middle-to-late 1960s, large fulltime "croaker boats" were employed and fishing effort expanded west of the Delta (primarily when stocks were unavailable east of the Delta).

Catch rates are seasonally variable, the highest rates being made on new recruits (May-July) and spawners (October-November). Catch rates decrease after the fall-winter spawning activity and continue to decrease through April. When new recruits enter the fishery, catch rates again increase to the summer highs.

Since 1976, croaker and bottomfish stocks have apparently decreased, particularly east of the Mississippi River. Increasing operating costs coupled with increasing effort by the shrimp fleet may have the net result of overfishing east of the Delta. Reduced catch rate may also be a function of the reductions in fleet size and in search time for exploitable stocks. Catch per unit of effort (CPUE) has remained reasonably constant for the past several years. Values for CPUE are about the same for both good and poor years, even though total biomass, croaker biomass, and yield values have decreased.

Table 1. Relative biomasses (in metric tons, mt) of bottomfish stocks and percentage contributions by major species in November surveys by the NMFS vessel OREGON II.

Species	Cruise Number and Year						
	42-72	48-73	55-74	62-75	71-76	83-77	92-78
	East Delta						
Total Bottomfish (mt)	45,331	84,380	90,485	80,176	52,128	28,839	51,846
Croaker	24	50	52	47	24	35	20
Spot	6	19	22	10	13	4	5
Sand seatrout	8	5	8	5	6	4	2
Silver seatrout	-	1	1	-	2	-	-
Catfish	36	9	3	10	2	2	7
Atlantic cutlassfish	-	1	1	2	1	2	-
Summation	74	85	87	74	48	47	34
	West Delta						
Total Bottomfish (mt)	135,994	228,140	135,728	187,077	133,232	77,482	65,804
Croaker	38	52	68	50	34	51	53
Spot	12	3	6	7	31	8	10
Sand seatrout	4	3	4	4	5	1	4
Silver seatrout	3	2	5	1	2	1	1
Catfish	16	25	3	16	15	8	12
Atlantic cutlassfish	-	2	2	2	2	1	4
Summation	73	87	88	80	89	70	84

1. Alabama

Walter M. Tatum

Alabama's Public Law 88-309 program supports a shrimp monitoring and assessment program which consists of sampling of postlarvae in open water flats adjacent to marsh lands with a 6-ft beam trawl (50 hole/in webbing). Juvenile shrimp are also sampled with a 16-ft otter trawl constructed of 0.75-in bar nylon mesh with a codend liner of 0.25-in Ace nylon mesh, towed at 3 knots for 10 minutes and retrieved by hand.

Contents of the beam trawl samples are preserved in the field and transported to the laboratory for sorting, identification, and measuring. Otter trawl samples are normally sorted in the field, the shrimp retained in an ice cooler for later "work-up", and the bycatch discarded.

Six beam trawl stations (three in Mobile County and three in Baldwin County) are sampled every two weeks throughout the year. Sixteen otter trawl stations (eight in Mobile County and eight in Baldwin County) are sampled weekly during April, May, and June to monitor brown shrimp size in conjunction with opening and closing of the shrimp season. Following the brown shrimp opening, monthly otter trawl samples are taken until August, at which time bi-weekly sampling is initiated to determine emigrating white shrimp size.

2. Louisiana

Claude J. Boudreaux

Intensive field studies of brown shrimp (Penaeus aztecus) began in the Barataria Bay area of coastal Louisiana in 1961 and expanded in the mid-1960s with the institution of coastal study areas. Each coastal study area is occupied by a resident crew led by a Wildlife and Fishery Biologist. This biologist conducts routine monitoring of fishes and shrimp in the estuaries and also undertakes research to develop information needed for management of the State's coastal fishery resources.

Over the years since the mid-1960s, approximately 65 stations have been sampled on a weekly basis from March through November. Approximately 24 of these stations are sampled with a 16-ft trawl, 25 with a 6-ft trawl, and 16 with 1/2-m plankton net. This survey had provided information needed for setting opening dates of regular seasons and for setting special seasons. It has also allowed Louisiana to institute a zone concept in opening dates; i.e., opening various sections of the state in response to the shrimp population dynamics of that portion of the state.

In many of the 16-ft trawl samples all species caught are counted and measured (in 5-mm groups), therefore a considerable data base exists for bottomfish as well as shrimp in Louisiana's inshore estuaries. In 6-ft trawl samples and in plankton samples, only penaeid shrimp are counted and measured.

3. Mississippi

Thomas D. McIlwain

Beginning in October 1973, Mississipi established a continuing monitoring and assessment program to provide baseline data on 19 target species (Table 1). Twenty-eight stations in various habitats are sampled monthly or semi-monthly (Fig. 1). Sampling gear was selected to collect a variety of life history phases with emphasis on the estuarine juvenile stage. Gear includes 16- and 40-ft otter trawls with a 1/4-in mesh liner, a Renfro beam trawl and 50-ft bag seine. Hydrological and meteorological data are taken at each station with a summary of these data provided monthly.

Length and weight data for all fish species were collected from October 1973 through September 1976. Data for target species were electronic data processed (EDP) each month. Data for non-target species were prepared but not processed. Total number, biomass, and length range by station were recorded for non-target species from January 1977 through the present. Length and weight data for target species continue to be submitted to EDP. Data on selected invertebrates are more detailed. Carapace width, weight, sex, maturity stage and growth stage are recorded for portunid crabs. Length, weight, sex and ecdysis state are noted for penaeid shrimp. Length and weight data are recorded for loliginid squid. All data on these species were submitted to EDP monthly beginning in October 1973 and continue through the present. Monthly catch per unit of effort (CPUE) by gear type and salinity regime, length-frequency by salinity regime, and length-frequency by gear type are summarized in the form of tables and are available at the end of each month.

In addition to the estuarine monitoring of juvenile stages, plankton and micro-nekton tows were made. Clarke-Bumpus samplers fitted with No. 3 mesh nets were used for simultaneous plankton collections at the surface and bottom. Tows were made in each of the offshore barrier island passes monthly from October 1973 through September 1979 (Fig. 2). Micronekton tows were made at the surface and bottom with metered nets. These nets had a mesh opening of 1050 microns and a mouth diameter of one meter. Tows were made monthly at three stations south of the barrier island passes from July 1974 through September 1979. All species of fish, larvae and postlarvae of penaeid shrimp and portunid crabs, and the young loliginid squid were removed and identified. These data have been coded for EDP and are being analyzed.

An intensive sampling program for juvenile penaeid shrimp was begun in 1975 to provide additional data on growth and relative abundance in Mississippi Sound during the period prior to opening the shrimp fishing season in State waters. Nine trawl stations in Mississippi Sound are sampled once at night and once during the day on a weekly basis. Salinity and temperature of the water are measured at each station. Data are processed weekly and provided to the Bureau of Marine Resources and to adjacent states. Resultant data are used to predict the time when the 25th percentile of length distributions from population diagrams would reach 100 mm, which is used by the Bureau to decide on opening of the Mississippi shrimp season.

A population analysis of the juvenile bottomfish in the traditional shrimping grounds in Mississippi Sound before and after the opening of shrimp season is being conducted by the Gulf Coast Research Laboratory. The primary objectives of this research are to:

1. Estimate total mortality for each target species;
2. Determine species composition of the total catch;
3. Determine fish to shrimp ratios for target and non-target species;
4. Determine difference in day and night catches;
5. Determine growth and length-weight relationships of target species (Atlantic croaker, spot, sand seatrout and silver seatrout).

Table 1. List of target species, Fisheries Monitoring and Assessment, Mississippi.

Micropogonias undulatus	*Menticirrhus americanus*
Leiostomus xanthurus	*Cynoscion nebulosus*
Cynoscion arenarius	*Penaeus aztecus*
Cynoscion nothus	*Penaeus duorarum*
Arius felis	*Penaeus setiferus*
Peprilus burti	*Trachypenaeus similis*
Trichiurus lepturus	*Callinectes sapidus*
Brevoortia patronus	*Callinectes similis*
Harengula jaguana	*Lolliguncula brevis*
Mugil cephalus	

Figure 1. Location of stations.

Figure 2. Location of plankton and micro-nekton stations.

4. Texas

Richard L. Benefield

The Texas Wildlife and Fisheries Department samples brown and white shrimp throughout the year with the exception of January and is required by law to set the closed Gulf season on emigrating brown shrimp. The closed season is generally from June 1 to July 15; however, if shrimp leave the bay early the closure may be set as early as May 15.

Weekly samples for postlarval brown shrimp are taken during March in Aransas and Galveston Bays with marsh nets (1/2-m plankton net, 1-mm mesh, attached to a metal frame). Temperatures, salinity, tidal conditions, and wind velocity and direction are recorded at each sample site. In April and May, samples are collected with 6-ft bar seines and 10-ft trawls on a weekly basis in Aransas, San Antonio, Matagorda and Galveston Bays. The lower Laguna Madre is sampled twice monthly during this period. Size and numbers of small brown shrimp are monitored in order to predict movement to the Gulf.

Samples for shrimp are taken monthly during February-May with 20-ft trawls in Galveston, Matagorda, San Antonio and Aransas Bays. This program is designed to monitor large white shrimp in the bays during late winter and spring. The sampling frequency is increased to semi-monthly during June-December. Marsh net and 10-ft trawl sampling are added in June when postlarval white shrimp normally appear. The population is followed through the summer in order to supply prediction information on the availability of white shrimp for the late summer and fall harvests.

As a component of the shrimp project, there are records of all fishes caught at five randomly selected stations each month in 20-ft trawl samples. A finfish project tabulates all species caught in gill and trammel net sets and all juvenile fishes caught in 60-ft seine samples.

5. Texas

Mark E. Chittenden

Studies begun in October, 1977, by the Department of Wildlife and Fisheries, Texas A & M Univeristy, have focused on trawling programs for a Bryan Mound Project and a Sea Grant Project off Freeport, Texas. The nature of the station tracks has changed as these programs have evolved. Trawl sampling has been conducted on a monthly or semi-monthly basis during day and night hours as far offshore as 55 fm.

In general, each specimen of fish and penaeid shrimp is measured and identified, and almost all specimens of fishes have been preserved for detailed processing. These specimens are being used for analyses of the life histories and population dynamics of each species. The fish species now under active individual study as student theses and papers or as staff papers include: *Micropogonias undulatus*, *Cynoscion nothus*, *Cynoscion arenarius*, *Stellifer lanceolatus*, *Stenotomus caprinus*, *Peprilus burti*, *Centropristis philadelphica*, *Diplectrum bivittatum*, *Pristipomoides aquilonaris*, and *Priacanthus arenatus*. Manuscripts prepared but not yet published include *Arius felis*, *Trichiurus lepturus*, *Polydactylus octonemus*, and *Menticirrhus americanus*.

6. National Marine Fisheries Service

K. N. Baxter

The MEXUS-Gulf Project, a joint shrimp mark-recapture effort, is coordinated among the National Marine Fisheries Service, the Texas Parks and Wildlife Department, Louisiana Wildlife and Fisheries Department, Instituto Nacional de Pesca of Mexico, and the Sea Grant Programs of Louisiana State University and Texas A & M University. The tagging project, along with its associated retrieval aspect, is the first major cooperative shrimp research effort between the United States and Mexico.

Project objectives include determination of rates of growth and mortality, patterns of migration, and delineation of stocks. Shrimp are tagged with small, numbered plastic tags of various colors which cause minimal interference to the shrimp.

Since the tagging studies began in 1977, nearly 334,000 shrimp have been tagged and released in Louisiana, Texas and Mexico waters. For example, a total of 167,216 shrimp were released at Louisiana, Texas and Mexico inshore and offshore sites in 1979. The recovery rate was 6.1%.

Preliminary migration patterns as indicated by tag returns from 1979 Louisiana releases show a general westerly and inshore movement with some recoveries made west of Sabine Pass in Texas waters. Recoveries from Texas releases moved both east and southwest, some as far east as the mouth of the Mississippi River. A total of 73 shrimp tagged in Texas waters moved south into Mexican waters, while 51 shrimp tagged in Mexican waters were recaptured off the Texas coast in 1979.

Plans for mark-recapture experiments in 1980 include 23 inshore and offshore studies in Louisiana, Texas and Mexico waters. During the January cruise east of the Mississippi River, aproximately 8,000 tagged shrimp were released off the coasts of Louisiana, Mississippi and Alabama.

V. MODELS

1. A Marine Food Chain: Evidence for a Hypothesis

R. Warren Flint

Although the benthos may be crucial in understanding the dynamics of marine ecosystems, the contribution of benthic ecology to biological oceanography has not adequately defined energy transfers. The northwestern Gulf of Mexico shrimp fishery is one component of a marine ecosystem which may rely heavily upon benthic dynamics, but these relationships have not been quantified.

Through correlational research, a hypothetical model of the marine food web leading to shrimp production in the coastal waters was developed. This model drew together benthic-pelagic coupling in terms of primary production, zooplankton densities, and processes within the benthos. Using bibliographical data as well as data from a 3-yr study of the south Texas continental shelf, the concepts of this model were converted to a schematic food chain quantifying the flow of energy to the shrimp fishery. Superficially, the information developed from the exercise indicated that the productive Gulf shrimp fishery cannot derive all of its nutrition from the benthic infauna. Shrimp production was estimated to be approximately 40 mg C/m^2/yr on the shelf, while the benthic infaunal production was calculated as approximately 290 mg C/m^2/yr. Alternatives to the assumptions used to develop this marine food web were discussed and areas of needed research were identified. In addition, speculation was presented concerning the effect upon the marine ecosystem, in particular this shrimp food web, if a disturbance such as an oil spill should occur to the sea floor. The author should be contacted for a more thorough presentation of the model.

2. Conceptual Model for Regional Ecosystem Dynamics

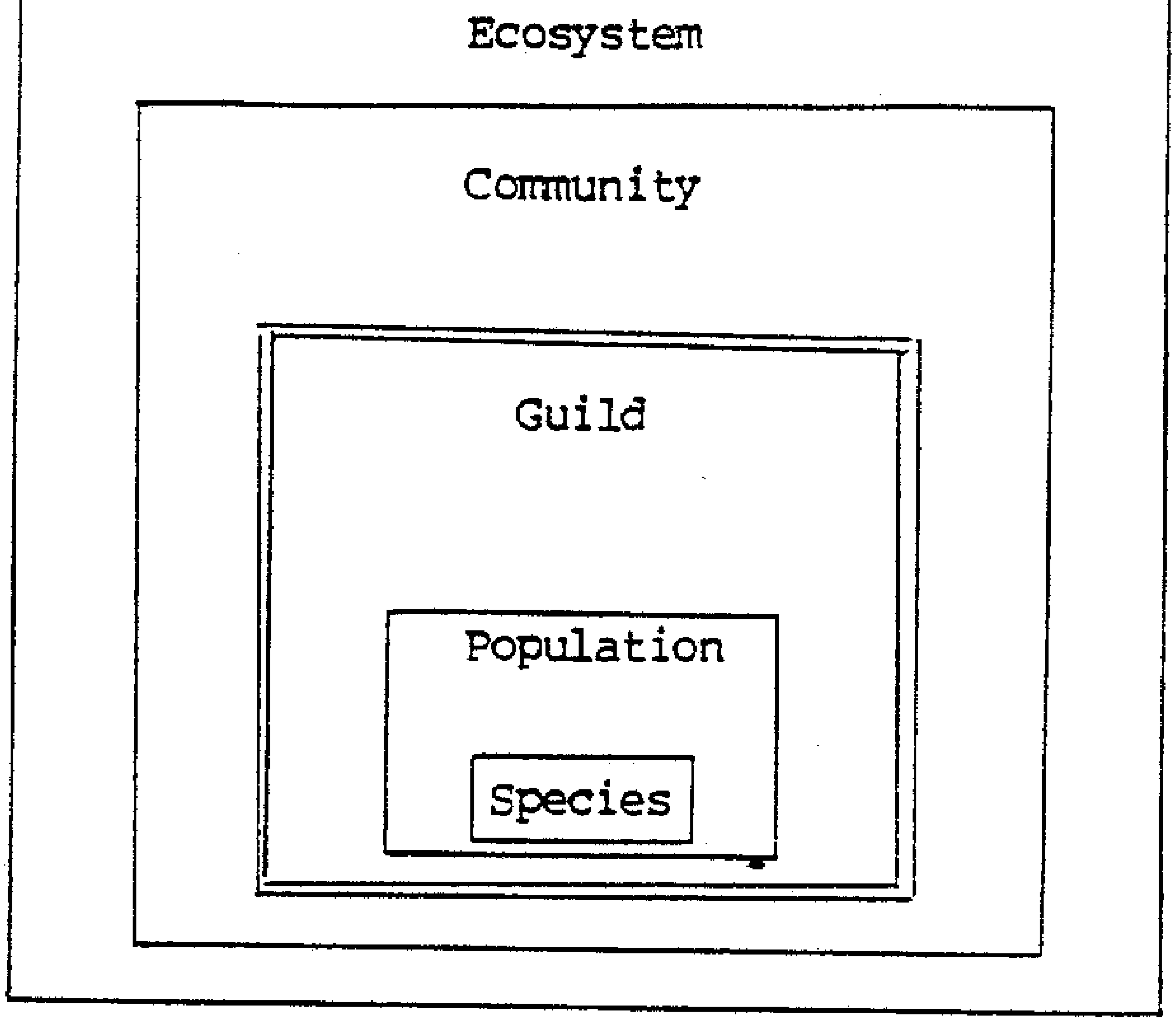
B. C. Patten

Ecology Simulations, Inc. (ESI) is developing a brine discharge impact assessment tool for the Strategic Petroleum Reserve (SPR) program. Since the required assessment methodology is to be developed within an ecological modelling context, ESI has constructed a comprehensive conceptual ecosystem model of the nearshore northwest Gulf of Mexico continental shelf. The conceptual model FRED (For Regional Ecosystem Dynamics) presented at this time is tentative. It is designed to be taxonomically exhaustive (Fig. 1): every organism known in the northwest Gulf of Mexico system is represented in one compartment at some degree of resolution. The model is thus flexible enough to consider both generic (regional) and site-specific (i.e., Bryan Mound) cases. The model is spatially undistributed, representing a column of water and biologically active sediments.

The model simulates conservative carbon flow dynamics of the system such that each carbon flow (Table 1) within the model is defined and controlled by temperature, salinity, and other physical and biological factors. Thus, the impact of the SPR brine disposal would be realized within the model as the indirect consequence of temperature and salinity perturbations upon the ecosystem's carbon flow structure and function.

The model is organized in hierarchical or nested levels (Fig. 1). Processes or structures at each subsequent level are progressively more resolved by five modules or submodels: PLANKTON, NEKTON, BENTHOS, ORGANIC COMPLEX and INORGANIC COMPLEX (Fig. 2). We emphasize that: 1) the hierarchical approach permits the model to be neatly expandable within the established framework according to the amount of detail required for a particular problem, and 2) the mediation of carbon flows by physical, chemical and biological factors approximates natural processes in this ecosystem simulator.

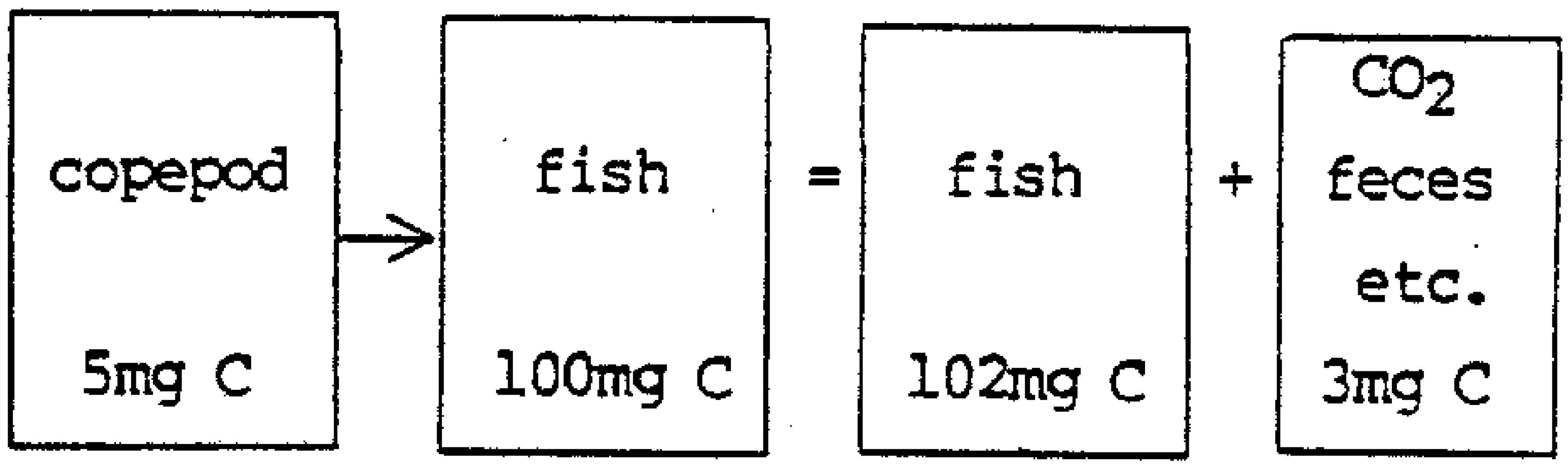
The NEKTON submodel is elaborated for illustration (Fig. 2). The guild concept is the basis for the NEKTON conceptualization. The seven compartments are formulated to reflect trophic ontogeny and defecation patterns. Unlike more traditional trophic compartmentalizations, this scheme permits one species to be represented in a single compartment throughout its life span from juvenile to adult and, therefore, allows the model to simulate its population dynamics (Tables 2 and 3).



I. Conservative process, such as

A. Energy

B. Biochemical



II. Nonconservative process, such as population dynamics

100 copepods $\longrightarrow$ 1 fish = 1 fish + ?

Figure 1. Hierarchical organization and associated processes for FRED.

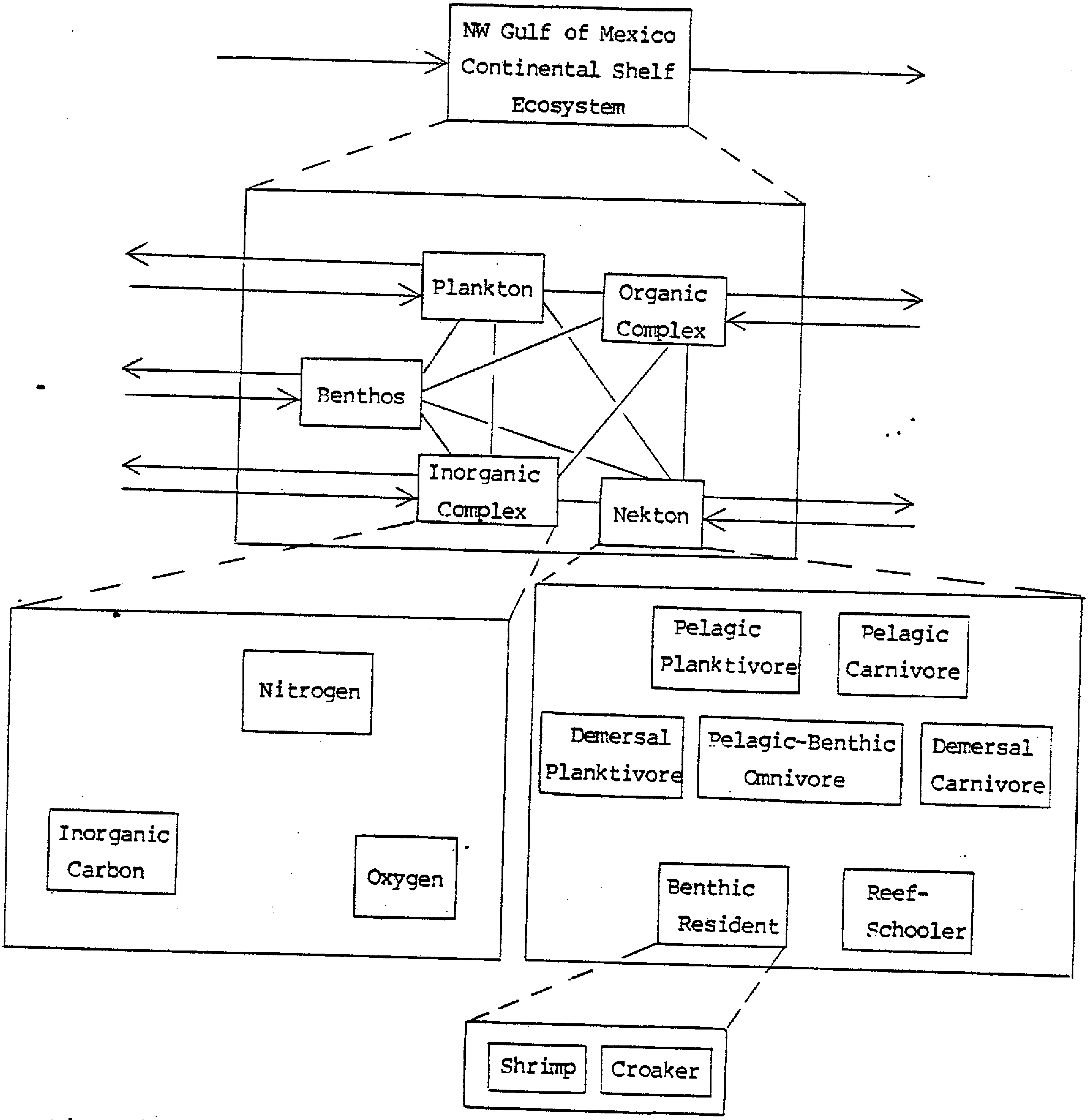


Figure 2. Component modules of FRED with further resolution of the nekton and inorganic complex components.

Table 1. Flow processes for FRED.

Carbon	Nutrients and Oxygen
feeding	incorporation
carbon fixation	mobilization
photosynthesis	equilibrium
adsorption	precipitation
reproduction	leaching
recruitment	auto-oxidation
defecation	excretion
secretion	import
mortality	export
harvest	
migration	
respiration	
fermentation	
physical transport	
resuspension	
sinking	
particulate formation	
aggregation	
fragmentation	
colonization	
equilibrium	
leaching	
molting	
import	
export	

Table 2. Representative species of the nekton in northwestern Gulf of Mexico.

Category	
11	*Cynoscion nebulosus*
13	*Cynoscion nothus*
14	Carangidae, Scombridae, *Menticirrhus*
21	*Brevoortia*, *Anchoa*
24	*Trachurus*, *Chloroscombrus*, *Peprilus*, *Loligo*
31	*Cynoscion arenarius*
33	*Saurida*, *Synodus*, *Porichthys*, *Lepophidium*, *Prionotus rubio*
43	*Prionotus stearnsi*
51	*Callinectes*, *Squilla*, *Leiostomus*, *Arius*
52	*Etropus*, *Trichopsetta*
53	*Serranus*, *Centropristis*, *Diplectrum*, *Stenotomus*
63	*Haemulon*
71	*Penaeus*, *Micropogonias*, *Stellifer*, *Pogonias*
73	*Upeneus*, *Halieutichthys*, *Ogcocephalus*

Table 3. Presence of species among nekton compartments according to migration pattern. Numbers are categories given in Table 2. Blank categories indicate absence of type species.

Compartment	Estuary: Winter Emigration	Estuary: Winter Immigration	Shelf Resident	Shelf Migrant
Pelagic carnivore	11		13	14
Pelagic planktivore	21			24
Demersal carnivore	31		33	
Demersal planktivore			43	
Pelagic-benthic omnivore	51	52	53	
Reef schooler			63	
Benthic resident	71		73	

The workshop on Shrimp-Bottomfish Interactions was subdivided into four working groups which were requested to identify major research questions and gaps, and then to determine what approach could be used to identify each research question within that working group. The working groups and the participants in each group were as follows:

1. Life History

   Participants: J. Y. Christmas, Carlton R. Hall, H. D. Hoese, Andre M. Landry, James M. Lyon, and Bernard C. Patten.

2. Bycatch

   Participants: Susan Durham, Steven L. Hollaway, Albert C. Jones, Thomas D. McIlwain, Sy Mendelssohn, Joseph E. Powers, W. R. Seidel, and Walter M. Tatum

3. Recruitment

   Participants: Craig Barber, K. N. Baxter, Richard L. Benefield, Claude J. Boudreaux, Joan Browder, Charles E. Comiskey, Paul Conzelmann, Elmer J. Gutherz, and Harriet M. Perry.

4. Food Chain Dynamics and Food Webs

   Participants: Michael A. Champ, Darryl L. Felder, Warren Flint, Larry Marx, Joseph E. Powers, Elizabeth Vetter, Zoula Zein-Eldin.

Other participants who did not work with a particular group but attended and contributed to the deliberations of the various groups included Charles W. Caillouet, Mark E. Chittenden, Edward F. Klima, Michael L. Parrack, and Sammy M. Ray.

1. Life History

Objective: Summarize biological information on the life history of shrimp and major bottomfish stocks of the northern Gulf of Mexico in order to obtain a better understanding of the ecology of shrimp and bottomfish communities.

The Gulf of Mexico Fishery Management Council recently identified "highest" and "very high" priority research areas for shrimp and bottomfish. Research priorities delineated by the Council include implementation (on a long-term basis) of programs developing information on a varied array of shrimp and bottomfish life history aspects. Population dynamics data, with particular reference to mortality, age and growth, habitat requirements, seasonal abundance, and recruitment, are essential not only to the development of practical management plans for shrimp and bottomfish but also in an understanding of the interactions between the communities. The shrimp fishery harvests appreciable quantities of bottomfish while fishing for shrimp. The effect on the bottomfish and shrimp communities of directed fishing by the shrimp and bottomfish fisheries is unknown. Basic ecology and life history requirements of these important species must be fully understood prior to making a scientific appraisal of the impact of directed fisheries on these communities.

The council also has identified particular target species for which these data are essential, including commercially important shrimp of the genus Penaeus [brown (P. aztecus), pink (P. duorarum) and white (P. setiferus)] and six finfishes [Atlantic croaker (Micropogonias undulatus), Atlantic cutlassfish (Trichiurus lepturus), sand seatrout (Cynoscion arenarius), sea catfish (Arius felis), silver seatrout (C. nothus), and spot (Leiostomus xanthurus)]. These fish species comprise nearly 90% of the bottomfish biomass caught between Mobile Bay, Alabama, and Point La Fer, Louisiana.

State and federal management agencies have amassed an appreciable volume of data on biological resources of the Gulf during the last 25 years. These field monitoring studies increased in number and size as the need to manage commercially important resources such as shrimp stocks became crucial to coastal economies. Most monitoring programs have had very specific but different objectives, each based on a particular fishery and management strategy. Data sets on shrimp stocks of the Gulf are voluminous but differ in quality and quantity with regard to species, area, and management priorities. Information on certain bottomfish species also is plentiful. However, few data are available for other abundant bottomfishes and even fewer data exist on interactions between shrimp and bottomfish communities. Major data sources identified are as follows:

1. National Marine Fisheries Service 5-year shrimp sampling survey of the northwestern Gulf of Mexico, 1961-1965.

2. Texas Parks and Wildlife offshore shrimp sampling survey of the Texas coast, 1975 to present.

3. Texas Parks and Wildlife shrimp and finfish sampling survey conducted in Texas bays and estuaries, 1964 to present.

4. Louisiana Wildlife and Fisheries shrimp and finfish sampling survey conducted in Louisiana bays and estuaries, 1966 to present.

5. Gulf Coast Research Laboratory shrimp and finfish sampling survey conducted in Mississippi Sound, 1972 to present.

Prior to initiating new large-scale monitoring programs, the existing information must be inventoried and synthesized. This approach is necessitated by uncertainties concerning quantity, quality, and location of data generated for Gulf shrimp stocks, contiguity of these data sets across state boundaries, and availability of data on bottomfish stocks as well as the potential for gathering additional data whose redundancy might compromise their usefulness.

This inventory and analysis will answer questions such as what data are available, where are these data, how compatible are these data, how can existing data be used, what additional data are needed, and what direction should future programs take in the management of fishery resources. Answers to these questions and centralization of existing information on shrimp and bottomfish will provide the framework upon which a well-coordinated, cost-effective research plan can be established for the Gulf.

General Approach: Review and summarize biological information on the important shrimp of the genus Penaeus and six target species of bottomfish as identified by the bottomfish FMP and identify major weaknesses or lack of valid scientific information, especially in the following areas:

1. seasonal and geographic distribution and abundance;
2. seasonal and geographic variations in growth, survival, maturation, spawning, and recruitment;
3. feeding behavior and predator/prey relationships;
4. food chain relationships.

The general approach to summarizing this information can be met by a variety of means - contracting, inhouse review, or holding a series of workshops with specific objectives to synthesize these data.

2. Bycatch

Goal: Determine the quantity and evaluate the impact of bottomfish bycatch on the shrimp and bottomfish communities in the Gulf of Mexico.

Objective 1: Determine the amount and composition of the bottomfish bycatch in the northern Gulf of Mexico.

The quantity and species composition of the bottomfish bycatch from the directed shrimp fishery is presently being collected by direct observation at sea. These data will be invaluable in estimating seasonal and temporal patterns of bottomfish bycatch. Annual estimations of bycatch need to be developed. At present the only reliable method to estimate bottomfish bycatch is through observations at sea from a small sample of shrimp vessels. Projection of the ratios of bottomfish to shrimp catch are used to extrapolate the entire bottomfish bycatch of the entire fleet. The basis of this estimate assumes a good relationship between shrimp and bottomfish abundance. This relationship needs to be closely examined to determine its validity.

Objective 2: Define the ecological fate of bycatch discard.

Bycatch discard is a food source for a variety of organisms including birds, fishes, invertebrates, and microheterotrophs (bacteria and fungi). It is important to examine the partitioning of bycatch biomass among organisms under various conditions of bycatch composition and quantity, community composition, and environmental factors (water column depth, temperature, hydrodynamics, oxygen regime, etc.) as delineated by spatial and temporal discard patterns.

Contributing to spatial discard patterns is the extent of hydrodynamic movement of discard biomass. This could be addressed through drift studies to determine extent and density of discard biomass. _In situ_ data on quantity (proportion) and rate of ingestion by species (or groupings of similar species) of birds, fishes, and macroinvertebrates are necessary.

Preferably these data should be collected by direct observation, e.g., RUFAS or brave SCUBA. Microbial utilization should be characterized by mode (aerobic or anaerobic) and rate of metabolism. Data would be taken from in situ sampling of microbial communities and monitoring of oxygen dynamics associated with the bycatch discard situation. Laboratory studies could provide rates of decomposition.

The accomplishment of this objective requires some a priori knowledge of temporal and spatial patterns of bycatch discard and of quantity and composition of shrimp and bottomfish bycatches by various user groups. User groups were identified as commercial, bait, and recreational shrimp fisheries; industrial, trawl, and foodfish bottomfish fisheries; and bottomfish recreational fisheries. Relevant data currently exist for at least some of the commercial fisheries. Additional information, if required for the other fisheries, could be gathered through selective interviews, surveys, and sampling.

OBJECTIVE 3: Determine the dynamics of shrimp and bottomfish stocks as a baseline for measuring the ecological effect of bycatch discard.

The group's intuitive opinion pinpointed bycatch as one probable cause of the allegedly lower bottomfish abundance, catch, catch rate or recruitment. However, quantitative data and a quantitative model of the shrimp and bottomfish stocks and fisheries are incomplete and will be a prerequisite to determining the ecological effect of bycatch discard.

It is initially important to establish the actual decrease in bottomfish stock size, as opposed to a repartitioning of bottomfish production among user groups. Reported landings of bottomfish declined in 1976-1979, but bycatch resulting from increased shrimping effort may have increased with total mortality on bottomfish remaining relatively unchanged. Examination of this possibility requires identification of all user groups and collection of statistics concerning catch, effort, CPUE, species and size composition, geographical area, and season for each group. Stock assessment and monitoring for species of interest would provide supplemental data, as would investigations of CPUE.

Secondly, it is important to determine the probable causes of reduced bottomfish stock size, assuming that reduced landings reflect reduced bottomfish populations. Five groups of factors affecting the bottomfish stock size were identified: 1) the type, amount, and carrying capacity of various habitats (estuarine, inshore, and offshore); 2) environmental conditions affecting survival (e.g., temperature, salinity, runoff, sedimentation, oxygen, meteorological phenomena); 3) toxic substances; 4) trophic relationships (e.g., food quality and availability, predation pressure, competition); and 5) fishery practices.

The development of population models is suggested to determine optimum biological yield and to assess the impact of harvesting strategies. These models should incorporate user groups, target species, species size, and gear types.

This working group's emphasis was directed toward identifying reduced juvenile recruitment as a causal agent of reduced stock size. Juvenile recruitment may be decreased by unfavorable inshore environmental conditions. To assess the effects of environmental factors on survival, it is necessary to determine the critical (sensitive) life stages and factors operating on survival at that time. Biological factors (trophic relationships) may affect recruitment as well.

Thirdly, it is important to determine the mortality in bottomfish stocks due to directed shrimp fishery bycatch. Of special interest is the effect of fishery practices, particularly shrimp bycatch, on juvenile bottomfish mortality. The group's intuitive opinion posited bycatch as a major cause of reduced bottomfish recruitment. Appropriate investigations would include the composition and quantity of bycatch taken by all user groups, identification of sensitive life stages, and mapping of impact zones.

Objective 4: Define the ecological effect of bycatch discard.

The accomplishment of this objective relies upon the results of Objective 3 and upon the existence or possible development of a good ecosystem model for the region of interest. Bycatch discard may induce low oxygen conditions. Although this condition is sometimes evident from trawling operations, it is a local phenomenon that is anticipated to have little effect on the ecosystem at large. Discard biomass is more likely to impact the ecosystem as a ready food source for four trophic groupings: 1) sea birds; 2) nektonic and demersal scavengers; 3) benthic invertebrates; and 4) microheterotrophs. As such, its total effect is not immediately apparent on species of commercial interest. This problem lends itself well to a modelling approach. Given a good regional ecosystem model, questions such as the following can be addressed:

1. What is the effect of reduction in bycatch discard due to changes in gear or harvesting practices?
2. What is the effect of reduction or complete removal of bycatch from the ecosystem due to changes in utilization practices?
3. Where are the impact zones associated with bycatch discard?

Answers to these questions, based on a thorough understanding of shrimp and bottomfish ecology, will provide information on the ecological role of bycatch and measures of the impacts of alternate ways of using the bycatch.

3. Recruitment

The working group was formed to consider the major research needs concerning the recruitment of shrimp and bottomfish in the northern Gulf of Mexico and to propose a general methodology for approaching these needs. The major points expressed by the group can be summarized as follows:

1) Development of an analytical framework for the study should be the first step in study design. Statistical analysis, hypothesis testing and conceptual ecosystem models were proposed as the analytical framework.

2) The study should be a cooperative effort of state and federal research groups. This approach is very important and should be pursued vigorously.

3) Data collection, processing, and management should be standardized. The formation of a Gulf of Mexico State-Federal Cooperative Resource Data Management Network accessable to all cooperators is suggested as a vehicle for this effort.

4) Historical data should be utilized to the fullest extent. To facilitate its use, historical data should be organized in the standardized format and placed on the common computer network. Historical data would potentially include biological sampling results and meteorological and hydrological data records.

5) The study team should be interdisciplinary and should include physical oceanographers and sedimentologists to help develop an understanding of the mechanisms by which the physical processes in estuaries affect fishery production.

Goals

1. Develop the capability to predict annual standing stocks of shrimp and bottomfish for use in estimating yield.
2. Evaluate the impact on shrimp and bottomfish production of proposed projects that can be expected to alter environmental conditions.

Objectives

1. Develop a prototype conceptual estuarine ecosystem model capable of being applied generally or to specific coastal units. Utilize the con-

ceptual model to organize information in a holistic (whole system) context.

2. Identify and computerize in a standardized format historical data bases and other information organized in the framework of the conceptual model.
3. Design and implement a hierarchial prototype sampling and analysis plan to characterize estuaries from the standpoint of their production of juvenile shrimp and bottomfish.
   a. Standardize data collection and reporting.
   b. Quantify the relationship between time-varying environmental and biotic parameters, annual recruitment to inshore and offshore fisheries, standing stocks in the estuaries and offshore, and indices of fishing success with adequate attention paid to characterization of population responses to catastrophic pulse events.
   c. Determine the characteristics of habitat that influence the production of juvenile shrimp and bottomfish, and document any changes through the historical record.
   d. Identify and quantify community interactions that are important to the productivity of the estuary with respect to shrimp and bottomfish recruits.
   e. Develop models (analytical tools) to quantitatively classify estuarine habitat with respect to the production of shrimp and bottomfish.
4. Develop and quantify a simulation model on the basis of the conceptual model and employ the simulation model for prediction of annual fishery yield and impact assessment.

General Approach

Factors of habitat and environment that affect survival and growth rates of shrimp and bottomfish separate naturally into two types: those that vary on relatively short time scales and those that vary over the long term or are relatively constant. Cutting across both categories is the catastrophic pulse event which occurs almost randomly. The proposed research approach addresses all three factors of habitat, as well as activities of man, that ultimately influence fisheries yield.

Specific Approach to Objective 1

Develop a general understanding of Gulf Coast estuarine ecosystems through a review of the literature and interviews with knowledgeable researchers regarding shrimp, bottomfish, estuarine ecosystems, and biological, geological, chemical, and hydrodynamic aspects of Gulf Coast estuaries.

Design a visual conceptual model incorporating known and hypothesized aspects of the structure and function of Gulf Coast estuarine ecosystems, including major trophic units, significant pathways of the flow of energy or materials, and physical, chemical, and biological controls.

Specific Approach to Objective 2

Organize historic and on-going federal and state data bases relevant to shrimp and bottomfish research into a Gulf of Mexico State-Federal Cooperative Resource Data Management Network. Potential data bases include:

1. Commercial fishery data bases (including Gulf Coast shrimp and finfish data)
2. Gulf of Mexico cooperative estuarine inventory data bases
3. Texas Natural Resources Information System
4. Texas Park and Wildlife estuarine studies
5. NOAA EDIS data bases which include all Strategic Petroleum Reserve data (Bryan Mound, Texoma, Capline)
6. Other major integrated studies (e.g., Buccaneer, STOCS, MADLA loop, Seadock, GURC, Corps of Engineers)
7. Louisiana Wildlife and Fisheries data bases
8. Corp of Engineers river discharge data
9. National Climate Center meteorology data
10. NNODC offshore physical oceanographic and meteorological data
11. STORET and BIOSTORET data bases from Environmental Protection Agency
12. NOS coastal tide, salinity and temperature data

In addition to the above, there is a substantial amount of data generated from theses, dissertations, impact assessment studies, etc., that may or may not be in computer-compatible form. We suggest that some effort be expended to ascertain the availability and location of some of the more pertinent of these data sets.

Specific Approach to Objective 3

The sampling program outlined below is linked to the structure of the evolving regional and site-specific conceptual estuarine models and is designed for maximum utility and minimum redundancy. It centers around the hydrologic cycle as the primary factor uniting the ecological system. The following specific approaches can be identified at this stage in the process:

1) Definition of coastal units: The first step in the development of a coordinated Gulf-wide hierarchical monitoring system with predictive and environmental assessment capabilities should be the definition and delineation of coastal units. The units to be studied in depth should be selected in order to adequately characterize the northern Gulf ecosystem as a whole. Bays with records of high production should be selected because of the long term data bases that are available.
2) Coastal characterization studies: Studies extremely pertinent to this proposed program are currently being conducted by the U.S. Fish and Wildlife Service. The National Marine Fisheries Service has developed a considerable historic offshore and estuarine data base utilizing the concept of statistical areas. Louisiana Wildlife and Fisheries considers seven hydrologic units along the Louisiana coast and bases its monitoring activities on these areas.

Within each coastal unit defined above, a long term monitoring program should be established that essentially standardizes methodology across the Gulf, being as consistent as possible with the historical record, the development of new sampling techniques, and the investigation of functional parameters in ecosystem processes. This project as consisting of three stages:

a. Intensive (spatially and perhaps temporally) one-year reconnaissance baseline studies in major habitat units within each coastal unit to identify "indicator" bays or estuaries. In areas where the baseline has already been established, effort can center on organization of the information in the context of present objectives.
b. Intensive one-year baseline effort aimed at detailed characterization of the "indicator" systems, with special emphasis on

the determination of "indicator" stations and parameters. Physical forcing functions operating in the estuarine system should be clearly identified. Existing data can be analysed in this context in lieu of a special collecting effort where adequate data are available.

c. Long term monitoring of "indicator" parameters at "indicator" stations in "indicator" bays. Parameters to be measured include both relatively stable habitat characteristics (i.e., land-water interface, sediment, vegetation type and biomass) and dynamic habitat parameters (i.e., salinity, temperature, and dissolved oxygen). Concurrent measurements of biotic standing stocks should be made.

Standing crop determinations for important biologic assemblages (communities) in the ecosystem should be made, with special and more directed effort toward the target species. These communities include demersal nekton, infauna, phytoplankton, zooplankton, and decomposers. The importance of larval stages (especially planktonic stages of target nekton species or groups) to the ultimate success of the populations should be recognized and considerable importance given to monitoring these stages.

Important environmental variables include:

a) Sediment parameters (grain size, labile organic carbon content)
b) Water temperature, conductivity, dissolved oxygen, transmissivity, and salinity
c) River discharge
d) Meteorological variables (wind, rainfall, Ekman transport, tides, solar radiation and air temperature)
e) Water quality (total nitrogen, total phosphorus, dissolved organic carbon, heavy metals, hydrocarbons, PCB's and other synthetic toxins, and suspended solids).

Important functional parameters include trophic relationships, primary production, and decomposition.

The historical data base should be utilized to its maximum potential for sample design optimization. Each estuarine area should be subdivided into at least the marsh and open bay areas. The group recognized the importance of the distribution of shrimp and finfish within an estuarine system and the importance of their migration from the marsh to the larger open bay areas where they are subject to the recreational and commercial inshore trawl fisheries. Within the marsh area, biomass and spatial distribution of the plant communities should be determined.

The development of the study design should investigate the ability of remote sensors and other state-of-the-art techniques to provide synoptic coverage on relevant system variables: (a) short-term variables such as chlorophyll concentrations, turbidity, temperature and salinity, and (b) long-term variables such as the spatial distribution and biomass of marsh vegetation. Employing these techniques and coordinating field collections with remote sensing activities will provide sea truth to develop remote sensing information and expand the coverage of field study information.

Possibly a single target system should be designated and primary efforts devoted to understanding that system in order to project the information to other systems. This approach could provide a clue as to how the systems differ or as to the importance of these differences biologically or to the fisheries in question.

The sampling frequency necessary to adequately characterize the habitat for a given parameter will depend on the inherent variablity which the parameters express through time. Therefore, the more actively varying parameters (e.g., salinity) may have to be sampled more frequently than less dynamically varying parameters. It is possible, at least for the long-term phase in this project ("indicator" stations at "indicator" bays monitored over a long period of time), that continuous in situ recorders would be worthwhile and cost effective. While the sampling program should be standarized across the study region, it is recognized that there will be need for site-specific modifications for almost any coastal region. For example, one of the primary purposes of the ongoing state programs is the need to be able to regulate the shrimp fishery. To do this, more intensive sampling is temporarily required during times of the year that differ across the Gulf (consistent with the longshore gradient in periods of spawning and subsequent migration of postlarvae in the northwestern Gulf).

The group stressed the need for a firm, basic experimental design for the effort, with site-specific considerations superimposed on this basic design, emphasizing the importance of integrated, goal-directed research guided by conceptual models and developed through statistical and simulation analysis.

Analytical questions to be addressed include:

1) Are there consistently quantifiable relationships between offshore fishing success and:
   a) inshore juvenile stock densities,
   b) inshore and offshore environmental variables,
   c) relevant biotic variables,
   d) inshore shrimping effort?
2) Are there consistently quantifiable effects of catastrophic pulse events such as hurricanes, floods, and freezes on:
   a) juvenile stock densities,
   b) juvenile condition factors,
   c) offshore fishing success?
3) Are there consistently quantifiable responses (i.e., migration) of estuarine stocks to non-catastrophic environmental pulses?
4) Are there consistently quantifiable relationships between simultaneous juvenile shrimp stock densities and juvenile bottomfish densities?
5) Are there consistently quantifiable relationships between juvenile stock densities and:
   a) environmental variables,
   b) relatively stable habitat features,
   c) inshore shrimping effort (for finfish this would represent the effect of bycatch)?
6) Are there statistically recognizable community groupings in the estuaries and how do these communities vary over time?
7) Do important demersal target species compete with each other for resources (food, space, etc.)?
8) What is the relation of recruitment to long-term trends in the fishery?
9) What are the primary factors associated with the duration and success of postlarvae and subadults in the estuary?
10) What regulations are necessary to protect nursery areas to assure viability of the demersal stocks?

The analytic scheme encompasses two major aspects, pattern analysis and hypothesis testing. Pattern analysis, based on a number of possible ecological similarity measures, essentially defines major trends within and between the data sets and identifies major trends and anomalies in the data set, thereby establishing a basis for formulating hypotheses. Both univariate and multivariate techniques can be employed in hypothesis testing, with discriminant analysis providing an especially strong tool. Once hypotheses are tested, new hypotheses are generated and the iterative process continues until all potential information available from the data is obtained. Pattern analysis includes similarity indices, cluster analysis, ordination analysis, factor/principal component analysis, canonical correlation analysis, and discriminant analysis. Hypothesis testing includes simple and multiple linear regression, simple and multiple correlation analysis, analyses of variance and covariance, time series analysis, and response surface analysis.

Specific Approach to Objective 4

The conceptual model undergoes refinement as additional information about the system is obtained from observations and data analyses. After considerable simplification, taking care not to lose important functional processes or relationships, the refined conceptual model forms the basis for development of a simulation model to be executed on a digital computer. Mathematical relationships are to a certain extent inherent in the conceptual model design and mathematical equations are easily developed from it. The mathematical model is essentially a set of differential equations representing the various compartments of the model with their flows of energy, biomass, carbon, or materials. A computer model is written to incorporate the mathematical equations and iterate them, introducing inputs, monitoring state variables, and collecting and organizing outputs. Model quantification is accomplished by means of study results, augmented by historical records and literature values. The model is simulated first for verification (to be sure there are no programming bugs), then for validation. One of the most effective means of validating an ecosystem model is to introduce historic time series data as inputs and compare generated output time series to their historic counterparts. The ability to utilize this validation technique depends upon the availability of appropriate time series data. When data uncertainties occur in the quantification of a model, sensitivity analysis is important to determine model behavior under incremental changes in parameter values. Finally the model is run to test the effect of manipulations of various exogenous variables (forcing functions) on state variables and system outputs.

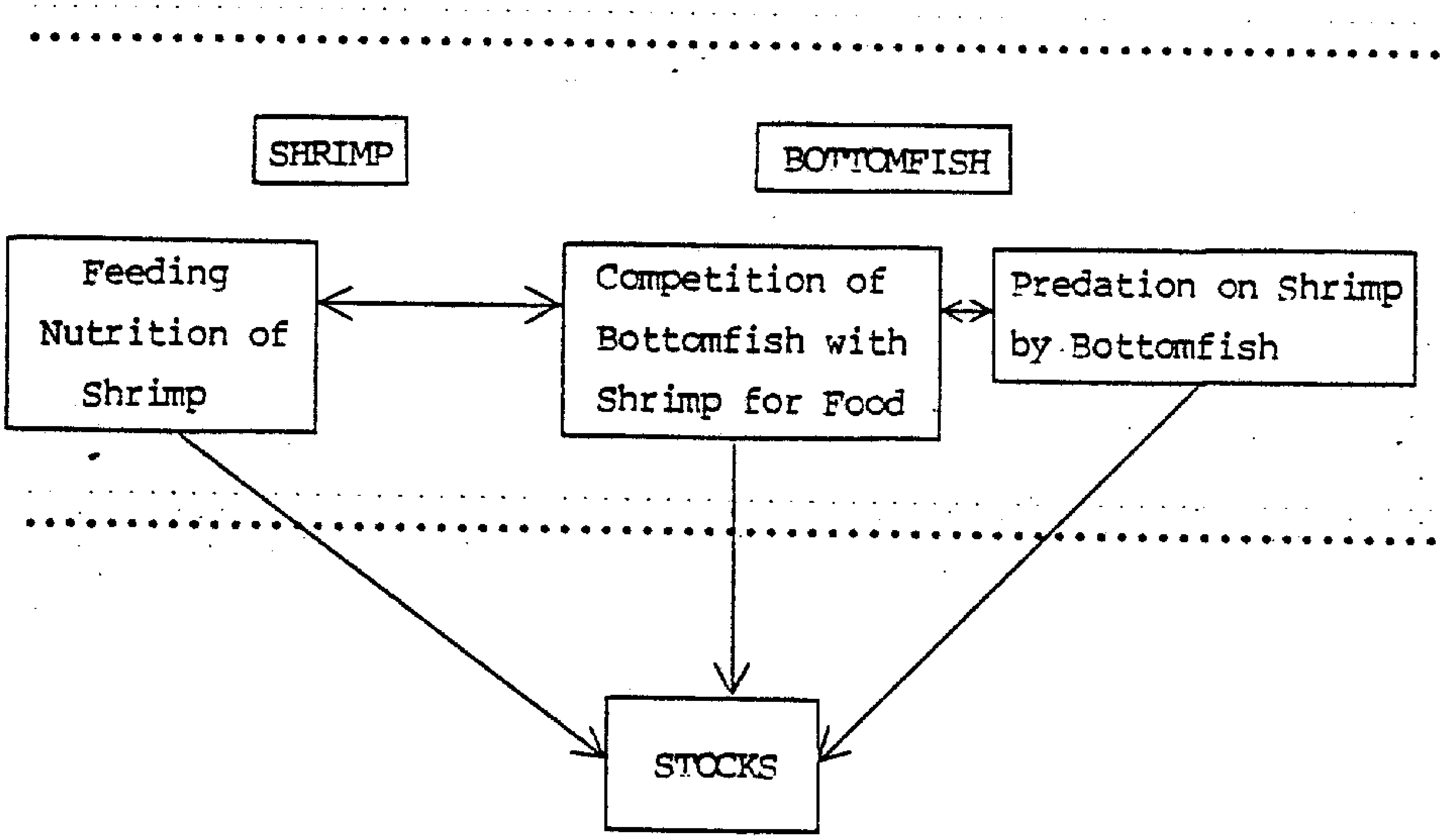
New information about the system results from simulation modelling. Furthermore, the entire modelling process helps to utilize resources most effectively and maximizes the potential for realizing research goals.

4. Food Chain Dynamics and Food Webs

Although considerable research has been directed to feeding and nutrition of penaeid shrimp in closed systems in recent years, food habits in nature are poorly known. The food habits and food chains of the major bottomfish species are also unknown, as are the predator-prey relationships between shrimp and bottomfish. This working group emphasized shrimp in determining research objectives and approaches to be used in achieving the stated objectives. With appropriate modifications, however, the same objectives and approaches can be applied to obtain required information on food chain dynamics and nutrition of the major bottomfish species.

A model of the interactions between shrimp and bottomfish is presented below:

MODEL OF INTERACTIONS



Three research objectives were proposed to investigate the food habits of penaeid shrimp. The specific objectives are:

1. Identify the various food items in the shrimp diet through controlled *in situ* experimentation, and contrast food intake to food availability;
2. Utilize laboratory feeding experiments to quantitatively assess shrimp preference for various food items eaten naturally in the field; and
3. Examine the efficiency of utilization of the various food items preferred by penaeids to assess the relative importance of these nutritional sources.

In the process of designing studies to achieve the proposed objectives, the group realized that the study sites should be representative of the various ecological regimes along the northern rim of the Gulf of Mexico (between the mouth of the Mississippi River and northern Mexico). Thus the establishment of specific study areas on a regional basis was recommended. Special emphasis was placed on 5 areas: 1) East of the Delta, 2) West of the Delta to Vermilion Bay, 3) West to Galveston, 4) South to Brownsville, 5) South of Brownsville. Within the specific study areas, studies would be conducted in selected habitats under similar environmental conditions. The studies would focus on the following size classes of shrimp: 15-20 mm, 35 to 40 mm, and 70 to 80 mm.

Approach for Brown Shrimp

A. Identification of food sources:
   - *In situ* double box experiment with/without shrimp for short term gut studies of starved shrimp.
   - Estuarine and coastal studies in different geographical areas down to 30 feet, associated with a seasonal cycle.

B. Are they selective? What is their preference and how does food availability affect preference?
   - Laboratory experiments of cultured food sources.
   - Laboratory and field studies varying substrate composition and food sources.

C. Identify and quantify all trophic links to shrimp:
   - Field and laboratory (via detritus, diatoms, meiofauna, microfauna, and macrofauna).

D. Determine relative assimilation efficiency of selected natural food resources in the laboratory.

E. Related special studies:
   - -- Enzymatic activity.
   - -- Evaluate the effects of developmental stages on functional morphology of feeding.
   - -- Effects of nutrition on reproduction.

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